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A partial wave analysis of the centrally produced K^+K^- system in pp interactions at 300 GeV/c

WA76/102 Collaboration

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Abstract

A partial wave analysis of the centrally produced K^+K^- channel from the WA76 experiment has been performed and shows evidence for peaks in the S-wave due to the $f_0(1500)$ and $f_J(1710)$ with $J=0$. The D-wave shows no evidence for a statistically significant contribution in the 1.7 GeV mass region. © 1999 Elsevier Science B.V. All rights reserved.

One of the fundamental predictions of QCD is the existence of glueballs. Current theoretical predictions based on lattice gauge calculations indicate that the lowest lying scalar glueball should be in the mass range 1500–1700 MeV [1]. The $f_0(1500)$ and the $f_J(1710)$ display clear glueball characteristics in that they are both produced in glue-rich production mechanisms and are either not seen, or are heavily suppressed in normal hadronic interactions. In addition, the $f_J(1710)$ is observed to decay dominantly to $K\overline{K}$ and yet it is not produced in K^-p interactions [2]. However, the spin of the $f_J(1710)$ is still uncertain with $J=0$ or 2 being possible.

Recently, the CERN WA102 experiment [3] has published the results of a partial wave analysis of the centrally produced K^+K^- system which shows that the $f_J(1710)$ has $J=0$. In 1989 the WA76 collaboration published results from the analysis of the centrally produced $K\overline{K}$ system [4]. In an attempt to assess the spin of the $f_J(1710)$ the angular distributions in the 1.5 and 1.7 GeV mass intervals were studied. The two regions were found to be similar, and since it was assumed that the signal at 1.5 GeV was due to the $f_2'(1525)$, it was concluded that the signal at 1.7 GeV was also spin two. From these two observations the $f_J(1710)$ was allocated spin two. However, the recent WA102 analysis [3] showed that the 1.5 GeV region had a large component due to the $f_0(1500)$.

This paper presents a reanalysis of the WA76 K^+K^- final state formed in the reaction

$$pp \to p_f(K^+K^-)p_s \qquad (1)$$

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at 300 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. The WA76 experiment has been performed using the CERN Omega Spectrometer, the layout of which is described in Ref. [5]. The main differences between this analysis and the previous analysis [4] is that in this analysis a full partial wave analysis has been performed. In addition, the much improved Omega simulation package developed for the WA102 experiment has been applied to the set up of the WA76 experiment. In addition, a kinematical fit has been performed on the data.

Reaction (1) has been isolated from the sample of events having four outgoing charged tracks, by first imposing the following cuts on the components of the missing momentum: $|$missing $P_x| < 20.0$ GeV/c, $|$missing $P_y| < 0.16$ GeV/c and $|$missing $P_z| < 0.08$ GeV/c, where the x axis is along the beam direction. A correlation between pulse-height and momentum obtained from a system of scintillation counters was used to ensure that the slow particle was a proton.

In order to select the K^+K^- system, information from the Čerenkov counter was used. One centrally produced charged particle was required to be identified as a K or an ambiguous K/p by the Čerenkov counter and the other particle was required to be consistent with being a kaon. The largest contamination to the real K^+K^- final state comes from the reaction $pp \to \Delta_f^{++} p_s \pi^-$ where the high momentum π^+ from the decay of the Δ^{++} is misidentified as a K by the Čerenkov system. In order to reject this contamination the positive particle was assigned the π mass and the $\Delta^{++}(1232)$ signal has been removed by requiring $M(p_f \pi^+) > 1.5$ GeV.

The method of Ehrlich et al. [6], has been used to compute the mass squared of the two centrally produced particles assuming them to have equal mass. A cut on the Ehrlich mass squared of $0.18 \le M_X^2 \le 0.56$ GeV^2 has been used to select a sample of 4 867 K^+K^- events.

The centrally produced K^+K^- effective mass distribution is shown in Fig. 1a. The main features of the spectrum are evidence for a sharp threshold enhancement and peaks in the 1.5 and 1.7 GeV regions.

A Partial Wave Analysis (PWA) of the centrally produced K^+K^- system has been performed assuming the K^+K^- system is produced by the collision of two particles (referred to as exchanged particles) emitted by the scattered protons. The z axis is defined by the momentum vector of the exchanged particle with the greatest four-momentum transferred in the K^+K^- centre of mass. The y axis is defined by the cross product of the two exchanged particles momenta in the pp centre of mass. The two variables needed to specify the decay process were taken as the polar and azimuthal angles (θ, ϕ) of the K^- in the K^+K^- centre of mass relative to the coordinate system described above.

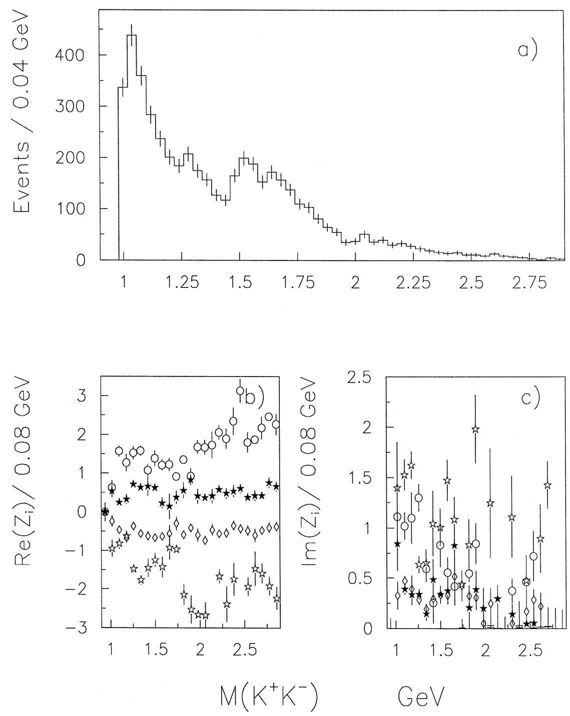

Fig. 1. (a) The K^+K^- mass spectrum. The (b) Real and (c) Imaginary parts of the roots (see text) as a function of mass obtained from the PWA of the K^+K^- system. The four symbols correspond to the four linked roots.

The acceptance corrected moments, defined by

$$I(\Omega) = \sum_L t_{L0} Y_L^0(\Omega) + 2 \sum_{L,M>0} t_{LM} \mathrm{Re}\{Y_L^M(\Omega)\} \tag{2}$$

have been rescaled to the total number of observed events and are shown in Fig. 2. As can be seen the moments with $M > 2$ and $L > 4$ are small

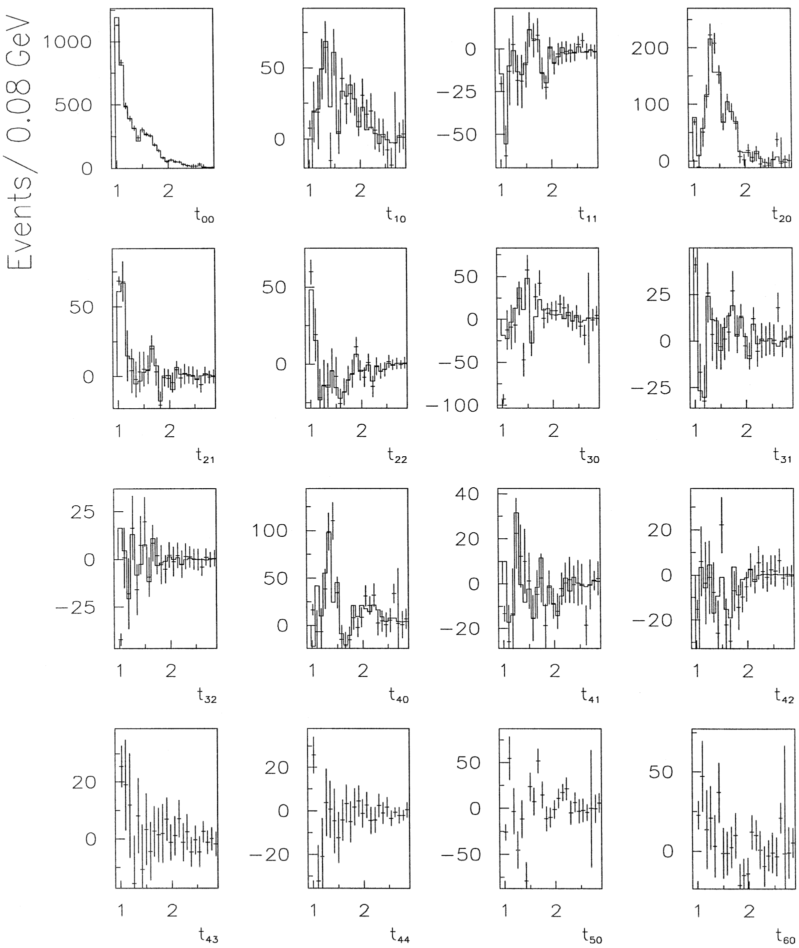

Fig. 2. The $\sqrt{4\pi}\, t_{LM}$ moments from the data. Superimposed as a solid histogram are the resulting moments calculated from the PWA of the K^+K^- final state.

(i.e. t_{43}, t_{44}, t_{50} and t_{60}) and hence only S, P, and D waves with $m \leq 1$ have been included in the PWA. The t_{00} moment represents the total acceptance corrected mass spectrum.

The amplitudes used for the PWA are defined in the reflectivity basis [7]. In this basis the angular distribution is given by a sum of two non-interfering terms corresponding to negative and positive values of reflectivity. The waves used were of the form J_m^ε with $J =$ S, P and D, $m = 0{,}1$ and reflectivity $\varepsilon = \pm 1$. The expressions relating the moments (t_{LM}) and the waves (J_m^ε) are given in Ref. [3]. Since the overall phase for each reflectivity is indeterminate, one wave in each reflectivity can be set to be real (S_0^- and P_1^+ for example) and hence two phases can be set to zero ($\phi_{S_0^-}$ and $\phi_{P_1^+}$ have been chosen). This results in 12 parameters to be determined from the fit to the angular distributions.

The PWA has been performed independently in 80 MeV intervals of the K^+K^- mass spectrum. In each mass bin an event-by-event maximum likelihood method has been used. The function

$$F = -\sum_{i=1}^{N} \ln\{I(\Omega)\} + \sum_{L,M} t_{LM}\epsilon_{LM} \qquad (3)$$

has been minimised, where N is the number of events in a given mass bin, ϵ_{LM} are the efficiency corrections calculated in the centre of the bin and

t_{LM} are the moments of the angular distribution. The moments calculated from the partial amplitudes are shown superimposed on the experimental moments in Fig. 2. As can be seen the results of the fit reproduce well the experimental moments.

Fig. 3 shows the $\cos(\theta)$ and ϕ distributions for the $f_0(1500)/f_2'(1525)$ and $f_J(1710)$ regions. These distributions differ from the ones presented in the original WA76 publication. Firstly, the analyser chosen in this PWA is the K^- not the K^+ as before which only has the effect of reflecting the events about $\cos(\theta)=0$ and has no other effect on the analysis. The second difference is that the ϕ distributions are considerable flatter in the present analysis. This is due to the improved Monte Carlo used in this analysis which has allowed a better acceptance calculation to be performed. In addition, the $\cos(\theta)$ distribution is flatter which is mainly due to the use of the kinematical fit performed. In the previous analysis the large deviations in ϕ meant that a $J_Z=2$ contribution was required in the fit which implied a $J=2$ component. Superimposed on the $\cos(\theta)$ and ϕ distributions is the result of the fit which describes the data well.

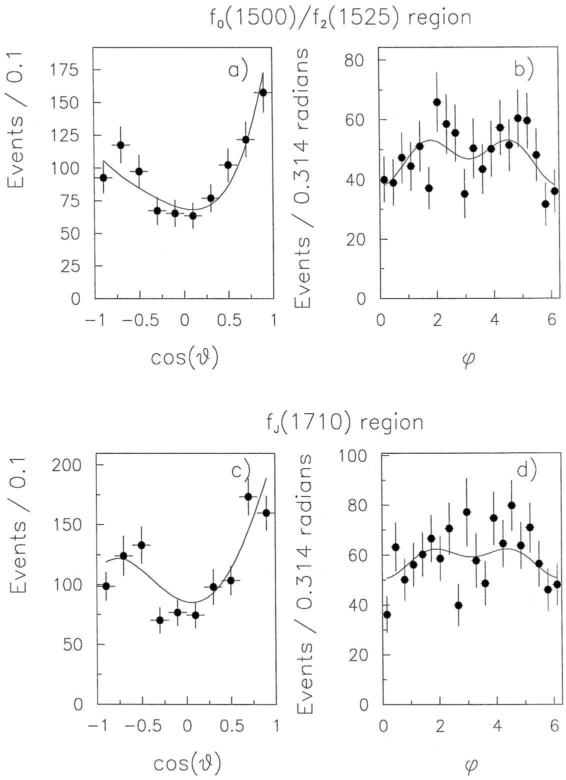

Fig. 3. The $\cos(\theta)$ and ϕ distributions for (a), (b) the $f_0(1500)/f_2'(1525)$ region (1.45–1.59 GeV) and (c), (d) the $f_J(1710)$ region (1.59–1.83 GeV) respectively. The superimposed curves are the result of the fit described in the text.

The equations that express the moments via the partial wave amplitudes form a non-linear system that leads to inherent ambiguities. For a system with S, P and D waves there are eight solutions for each mass bin. In each mass bin one of these solutions is found from the fit to the experimental angular distributions; the other seven can then be calculated by the method described in Ref. [7]. In order to link the solutions in adjacent mass bins, the real and imaginary parts of the Barrelet function roots are required to be step-wise continuous and have finite derivatives as a function of mass [8]. By definition all the solutions give identical moments and identical values of the likelihood. The only way to differentiate between the solutions, if different, is to apply some external physical test, such as requiring that at threshold the S-wave is the dominant wave.

The four complex roots, Z_i, after the linking procedure are shown in Fig. 1b and c. As can be seen the imaginary parts give little help in the linking procedure. However, the real parts are well separated in most places and hence it is possible to identify unambiguously all the PWA solutions in the whole mass range. In the 1.75 GeV mass region two roots do become close together, but if these two roots are swapped it results in events from the S-wave being transferred almost entirely into the P-wave and produces mass spectra that look unphysical. In addition, the zeros do not cross the real axis and hence there is no problem with bifurcation of the solutions. Near threshold the P-wave is the dominant contribution for five out of eight solutions, another is dominated by D-wave and another has the same amount of S-wave and P-wave. These seven solutions have been ruled out because the K^+K^- cross section near threshold has been assumed to be dominated by S-wave. The remaining physical solution is shown in Fig. 4.

Since the original WA76 analysis [4] did not perform a PWA from threshold and it was assumed that the peak at 1.5 GeV was dominated by the $f_2'(1525)$ it is likely that the solution chosen previ-

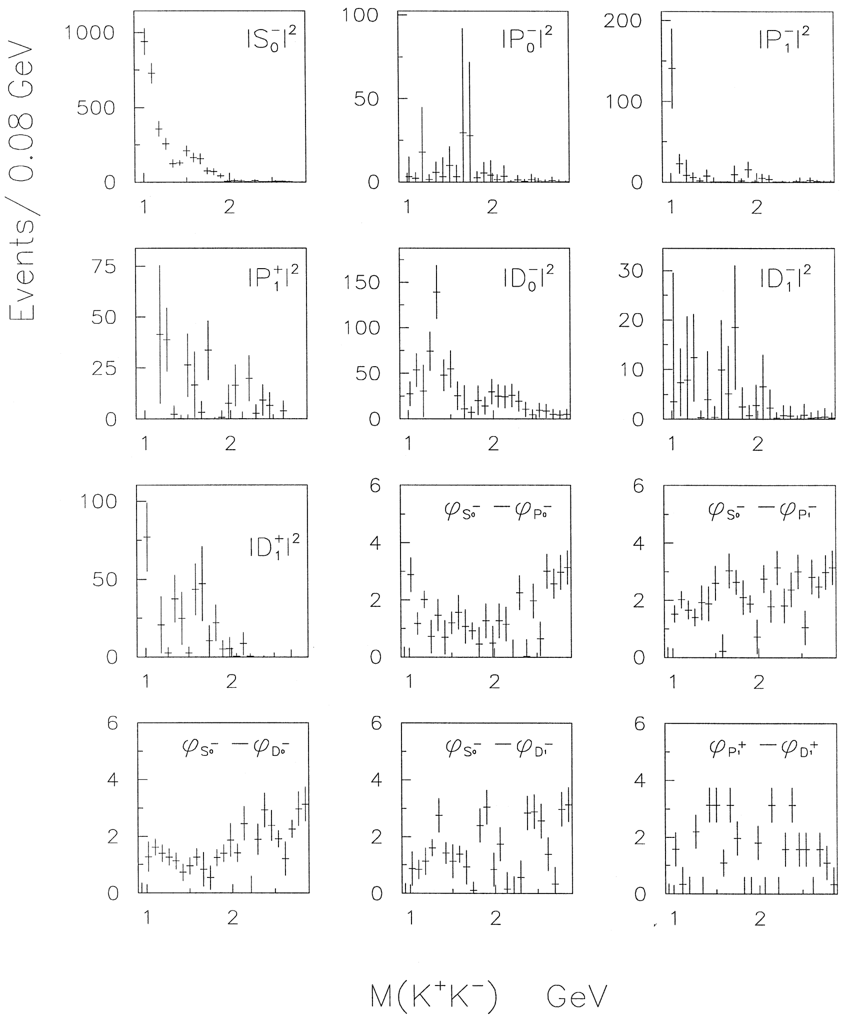

Fig. 4. The physical solution from the PWA of the K^+K^- final state.

ously was the one in which the D-wave dominates over the entire mass range. In this solution the S-wave from the physical solution is split effectively equally between the D_0^-, D_1^- and D_1^+ waves.

In the solutions dominated by P-wave at threshold the S-wave from the physical solution is split effectively equally between the P_0^-, P_1^- and P_1^+ waves. Since the K^+K^- mass spectrum is very similar to the $K_S^0K_S^0$ mass spectrum [4], with the exception of the ϕ, and since there can be no P-wave in the $K_S^0K_S^0$ channel we can also rule out these solutions.

In the present analysis the S-wave from the physical solution shows a threshold enhancement and a structure in the 1.5–1.7 GeV mass interval which has been interpreted as being due to the $f_0(1500)$ and $f_J(1710)$ with $J=0$. There is no evidence for any significant structure in the D-wave in the region of the $f_J(1710)$. In the P_1^- wave there is a peak in the bin corresponding to the $\phi(1020)$ which is consistent in size with the signal observed in the total mass spectrum [4]. These results are compatible with those coming from the WA102 experiment [3].

A fit has been performed to the S_0^- wave using the same parametrisation used in the WA102 analysis [3] namely; three interfering Breit-Wigners to describe the $f_0(980)$, $f_0(1500)$ and $f_J(1710)$ and a

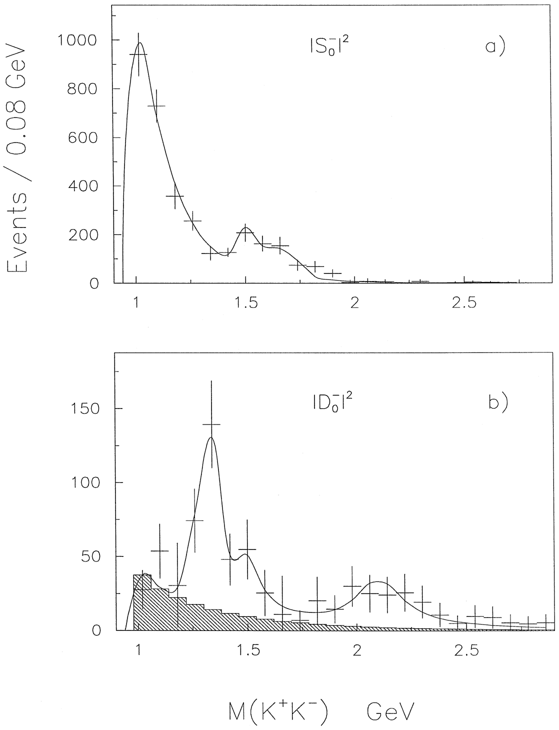

Fig. 5. The (a) S_0^- and (b) D_0^- waves with fits described in the text. The shaded histogram superimposed on the D_0^- wave is an estimation of the feedthrough from the S_0^- wave.

background of the form $a(m-m_{th})^b \exp(-cm-dm^2)$, where m is the K^+K^- mass, m_{th} is the K^+K^- threshold mass and a, b, c, d are fit parameters. The resulting fit is shown in Fig. 5a and gives

$f_0(980)$	$M=$	978 ± 15 MeV,	$\Gamma=$	60 ± 23 MeV
$f_0(1500)$	$M=$	1505 ± 18 MeV,	$\Gamma=$	100 ± 33 MeV
$f_0(1710)$	$M=$	1710 ± 25 MeV,	$\Gamma=$	105 ± 34 MeV

parameters which are consistent with the PDG [9] values for these resonances.

A fit has been performed to the D_0^- wave using three incoherent Breit-Wigners to describe the $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and the peak at 2.2 GeV and a background of the form $a(m-m_{th})^b \exp(-cm-dm^2)$, where m is the K^+K^- mass, m_{th} is the K^+K^- threshold mass and a, b, c, d are fit parameters. Included in the fit as a histogram is an estimation of the feedthrough from the S_0^- wave which is the dominant contribution to the D_0^- wave below 1.2 GeV. The resulting fit is shown in Fig. 5b where the parameters for the Breit-Wigners have been fixed to the values found by the WA102 experiment namely; for the $f_2(1270)/a_2(1320)$ $M=1305$ MeV, $\Gamma=116$ MeV, for the $f_2'(1525)$ $M=1515$ MeV, $\Gamma=70$ MeV and for the $f_2(2150)$ $M=2130$ MeV, $\Gamma=250$ MeV.

In conclusion, a reanalysis of the K^+K^- channel from the WA76 experiment has been performed. A partial wave analysis of the centrally produced K^+K^- system shows evidence in the S-wave for the $f_0(1500)$ and $f_J(1710)$ with $J=0$. There is no evidence for a statistically significant contribution in the D-wave in the 1.7 GeV mass region.

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